

Measurements of small aperture quadrupoles for the Linac4 and CLIC projects

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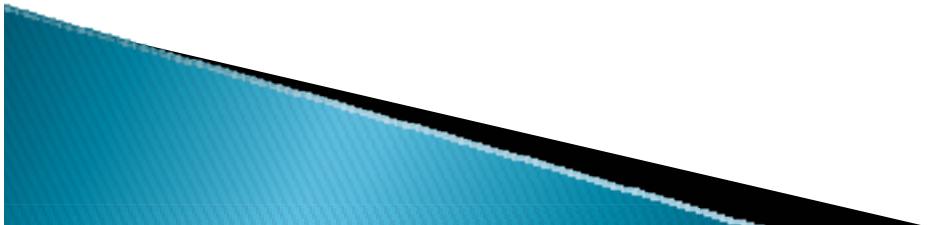
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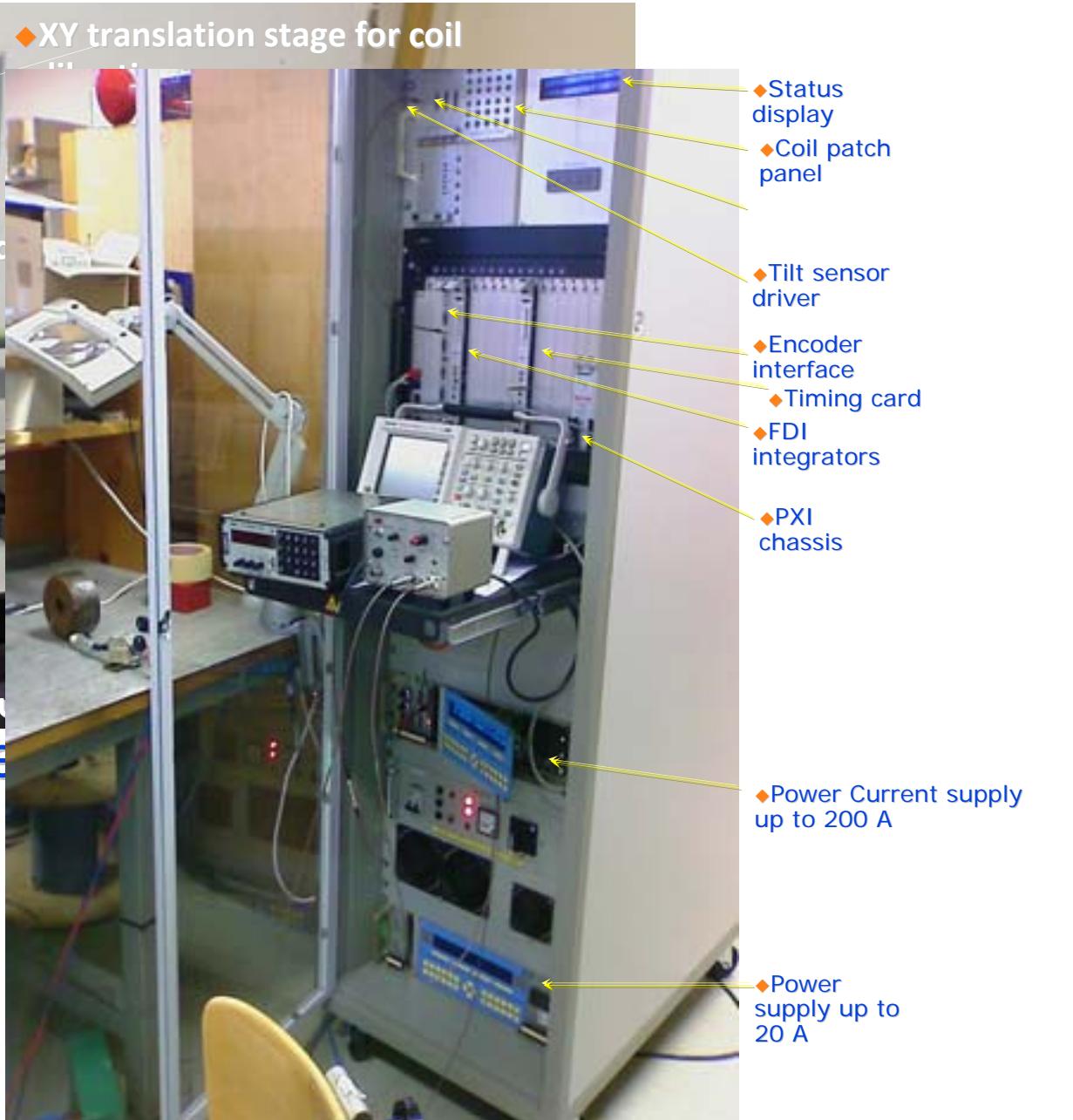
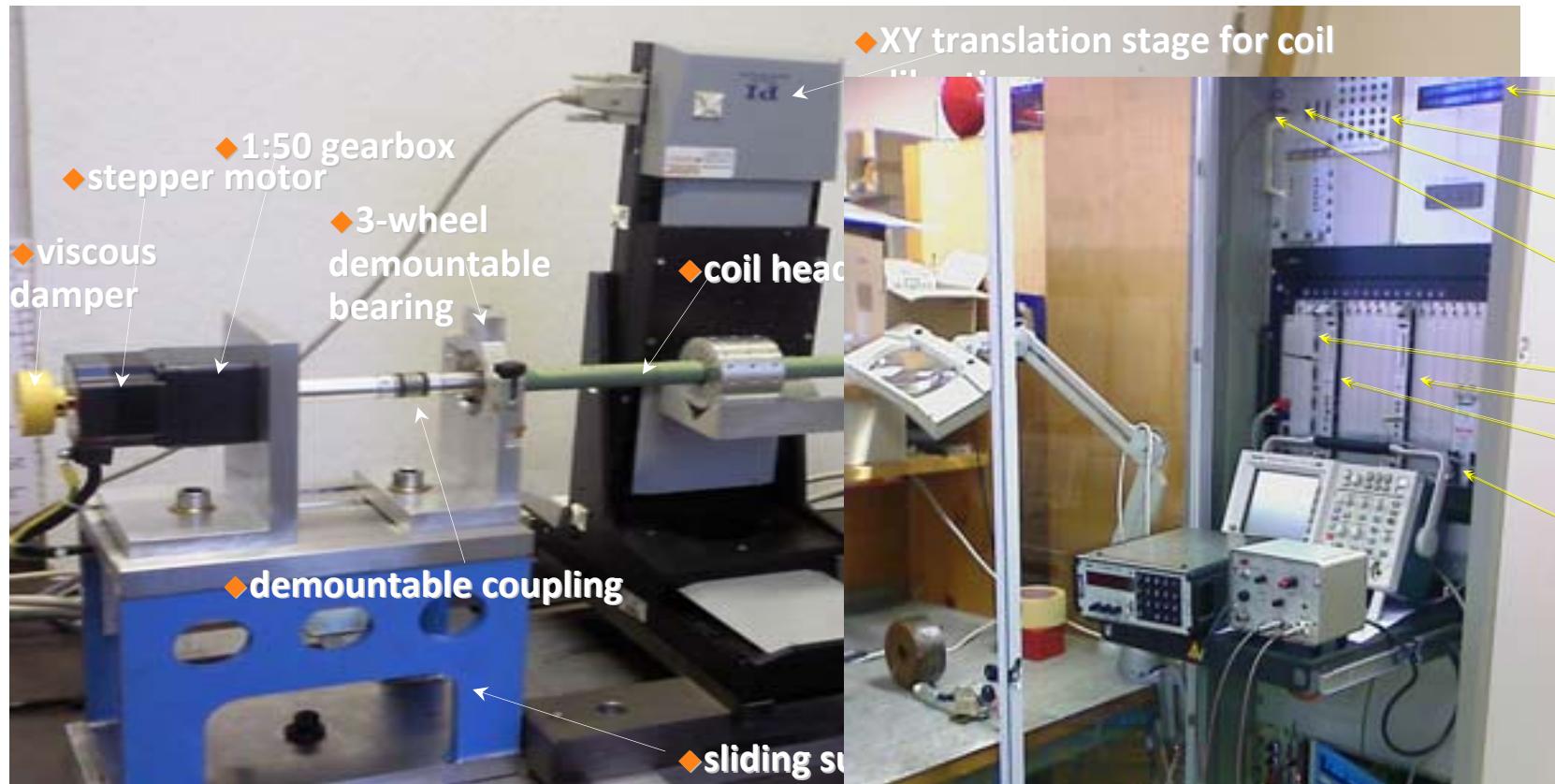
International Magnetic Measurement Workshop XVII
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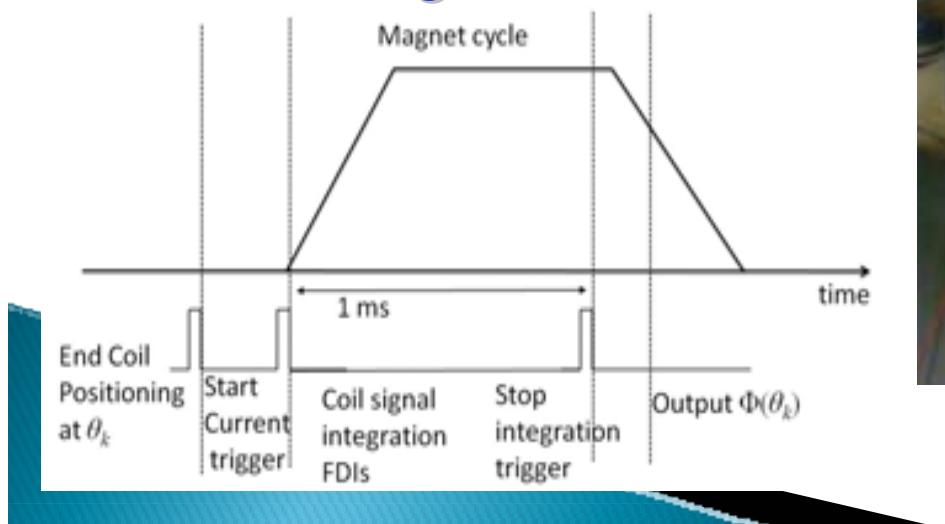
Overview

- ▶ LINAC4 bench update
- ▶ Geometrical-Axis measurements
- ▶ Harmonic measurements
- ▶ Linac4 magnets measurements
- ▶ CLIC magnets measurements
- ▶ Conclusions



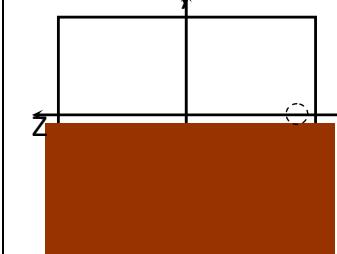
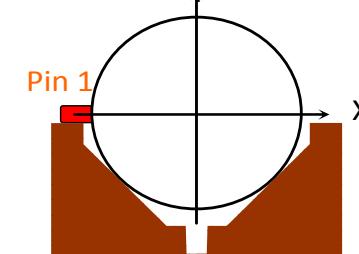
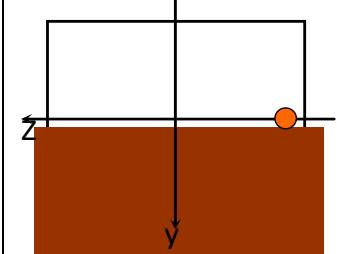
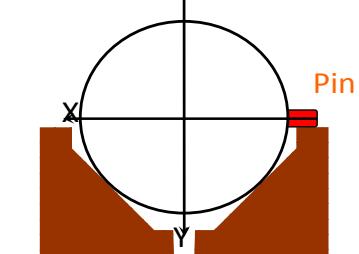
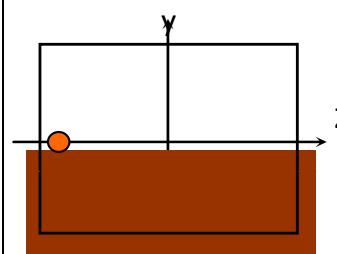
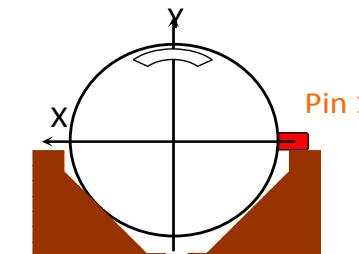
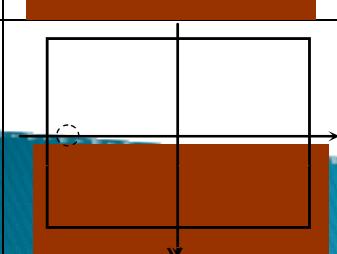
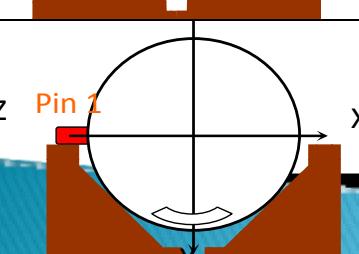


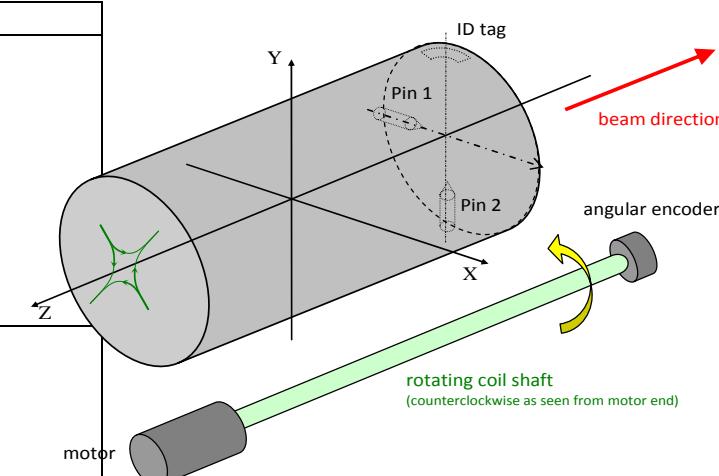
◆ Pulsed Magnet measurement



Ref. : O. Dunkel presentation at IMMW16 workshop

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position	Side/Frontal view	Notes
0	 	<p>Base position <i>Reference measurement (mandatory)</i> $\{ C_n = B_n + iA_n \}$</p>
1	 	<p>Base + 180° around Z <i>Measure X and Y offsets</i> <i>Check pin rests (recommended)</i></p> $B_n' = (-1)^n B_n$ $A_n' = (-1)^n A_n$ <p>(all odd harmonics change sign)</p>
2	 	<p>Base + 180° around Y <i>Measure field direction offset (recommended)</i></p> $B_n'' = (-1)^n B_n$ $A_n'' = (-1)^{n-1} A_n$ <p>(odd skew and even normal harmonics change sign)</p>
3	 	<p>Base + 180° around X $(= \text{Base} + 180^\circ \text{ around Y} + 180^\circ \text{ around Z})$</p> <p><i>Cross-check 1.2 and 1.3 (recommended)</i></p> $B_n''' = (-1)^{n-1} B_n$ $A_n''' = (-1)^n A_n$ <p>(odd normal and even skew harmonics change sign)</p>



turn around longitudinal axis

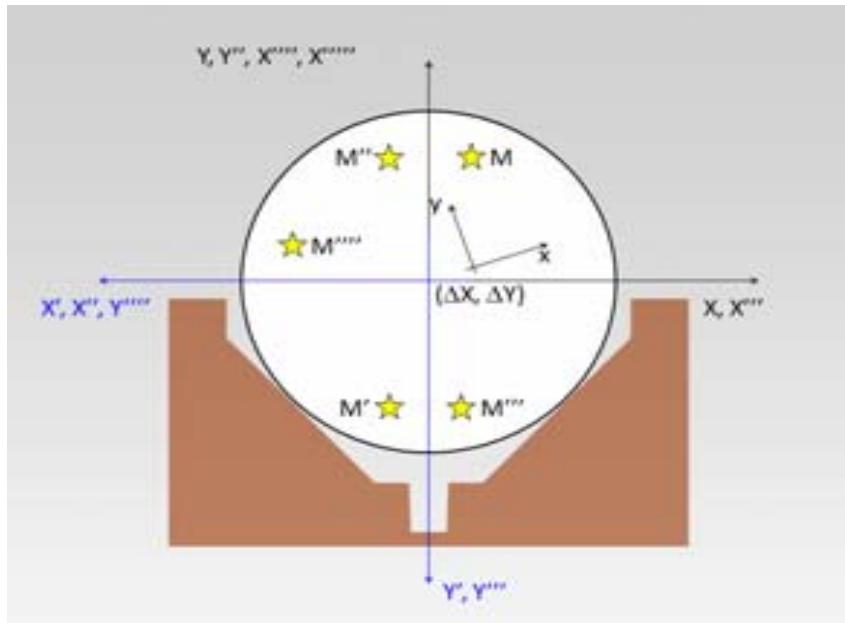
rectified pin rests

◆ flip around vertical axis

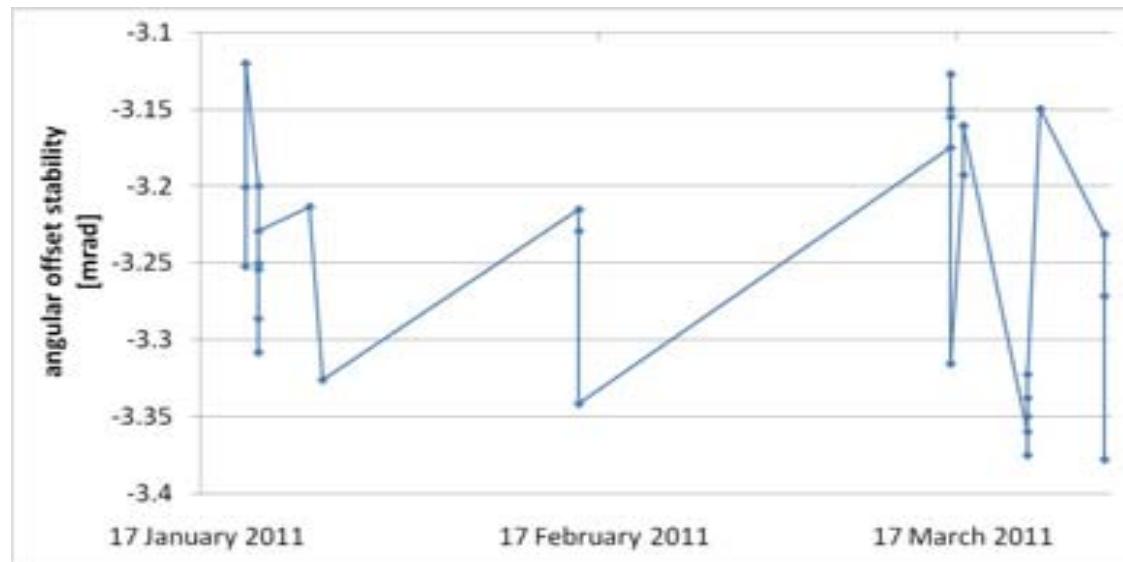
main objective:
link the fiducial references on the magnet to the test bench references (i.e. coil rotation axis, encoder zero)

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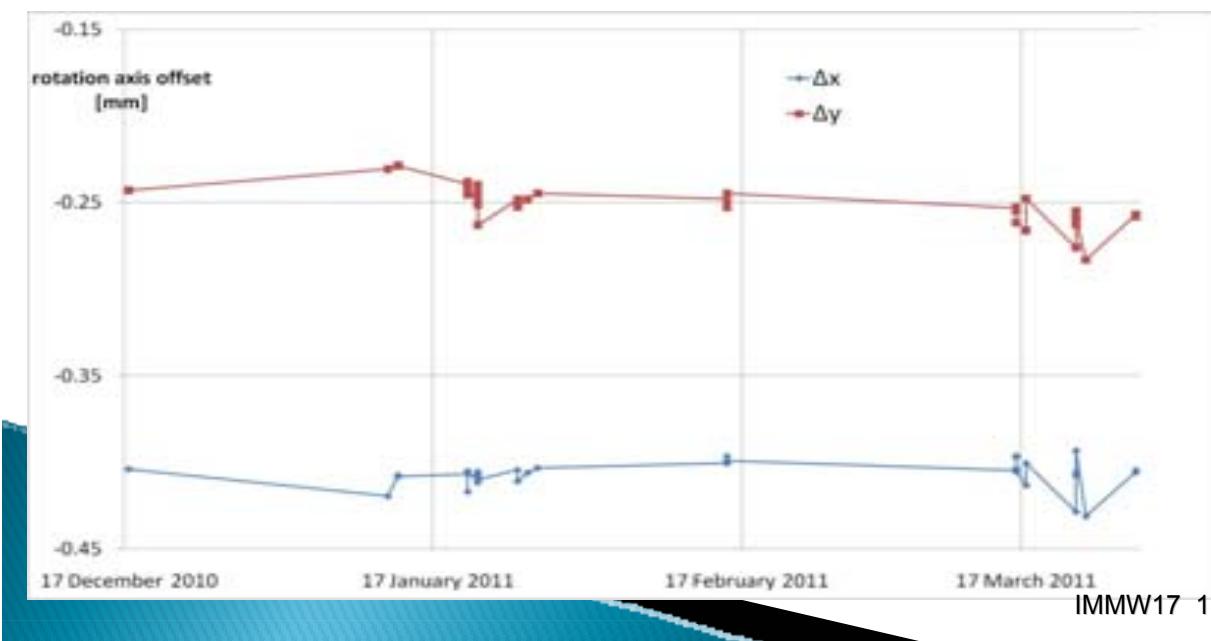
♦4



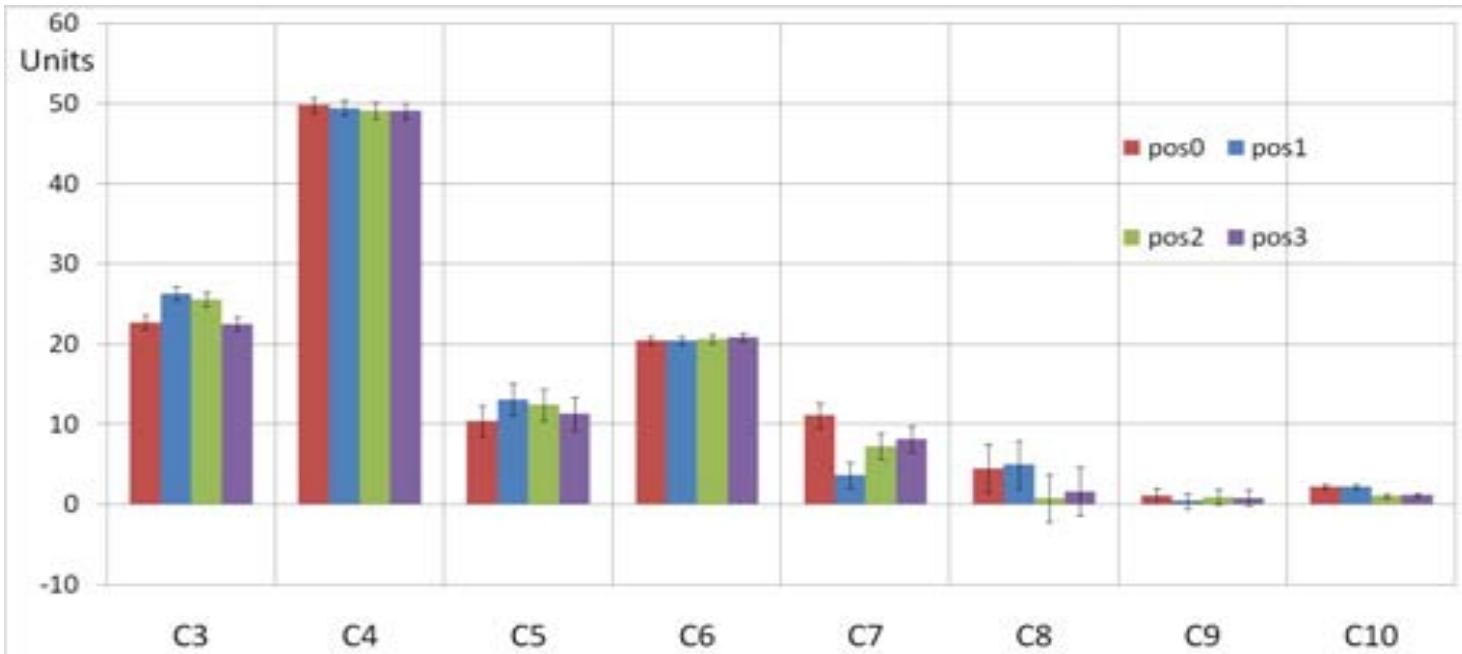
- ◆ Angle measurement uncertainty $\pm 60 \mu\text{rad}$
- ◆ all systematic Effects removed by flipping the magnet around the Y axis



- ◆ Stability of the angle $\pm 100 \mu\text{rad}$ in three months

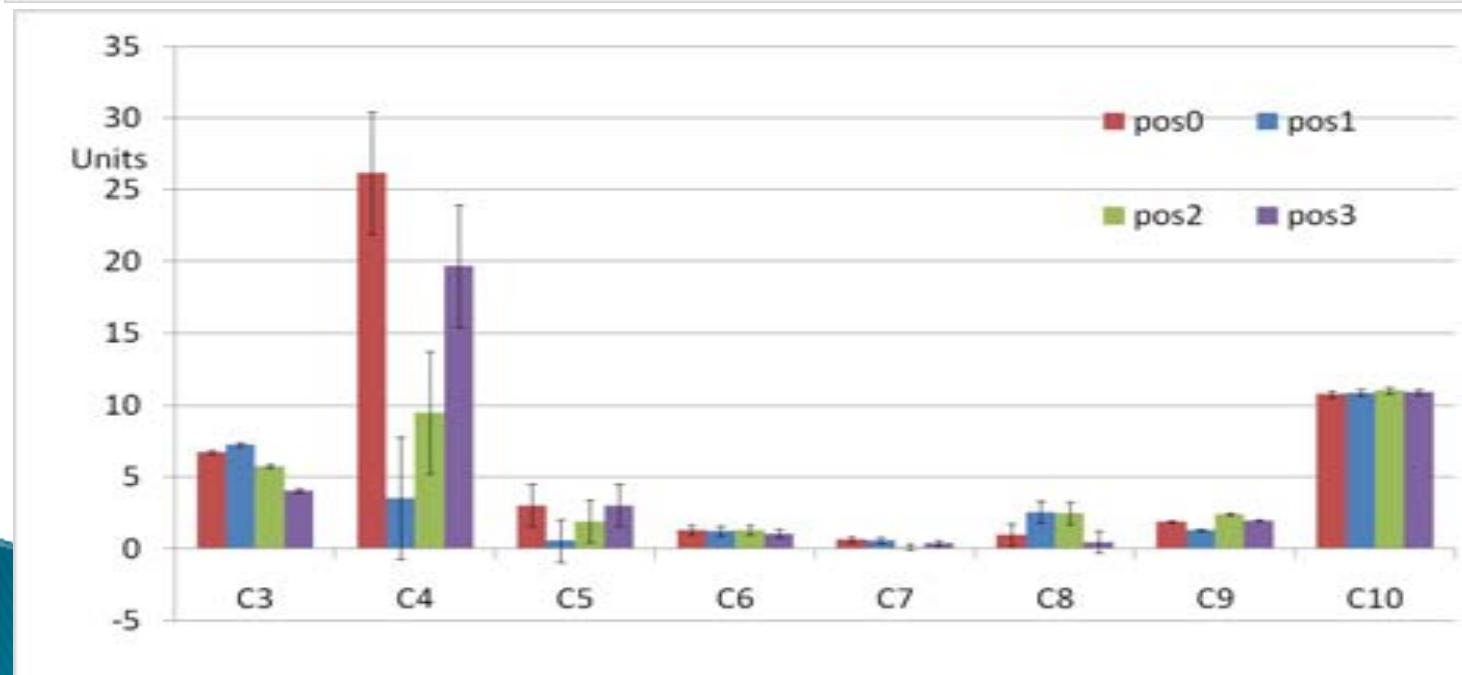


- ◆ Magnetic axis measurement uncertainty $\pm 10 \mu\text{m}$ all systematic
- ◆ Effects removed by flipping the magnet around the Z and Y axis
- ◆ Stability of the axis measurement $\pm 10 \mu\text{m}$ in three months



➤ Permanent magnet harmonic measurements in 4 different positions

- The absolute coil has low sensitivity to b_8, a_8 (new coil under construction)
- No systematic errors between the CERN measurement and the manufacturer
- Random differences with the manufacturer 0.04% RMS over 40 magnets measured



➤ Pulsed Quadrupole measurement step by step in 4 different positions

- 1 ms current cycle up to 200A
- current rise time 300 μ s
- The compensate coil is not sensitive to the b_4, a_4

Axis Measurements

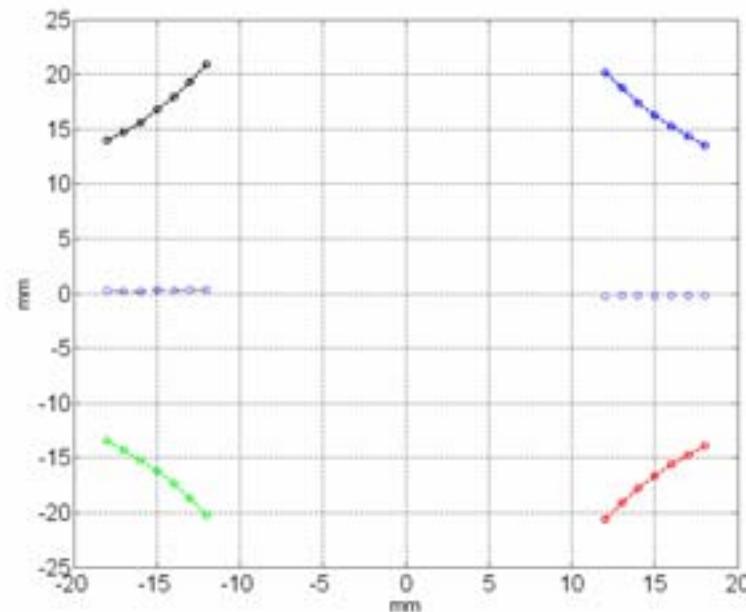
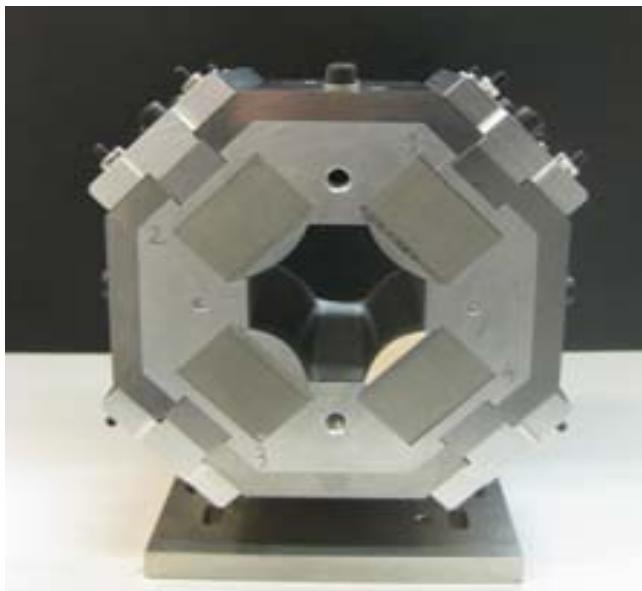
Permanent Magnet Quadrupole (CCDTL Linac4) prototype measurements

Main Characteristics:

- ✓ Aperture : 45 mm
- ✓ Integrated gradient (Max):1.6 Tesla
- ✓ Integrated gradient (Min):1.3 Tesla
- ✓ Inner diameter (Min):0.040 m
- ✓ Outer diameter (Max):0.200 m
- ✓ Length :0.100 m
- ✓ Gradient integral error (rms): \pm 0.5 %
- ✓ Magnetic versus geometric axis:< 0.1 mm
- ✓ Harmonic content at 15 mm radius: B_n/B_2 for $n=3,4,\dots$:< 0.05
- ✓ Yaw/pitch/roll:1 mrad



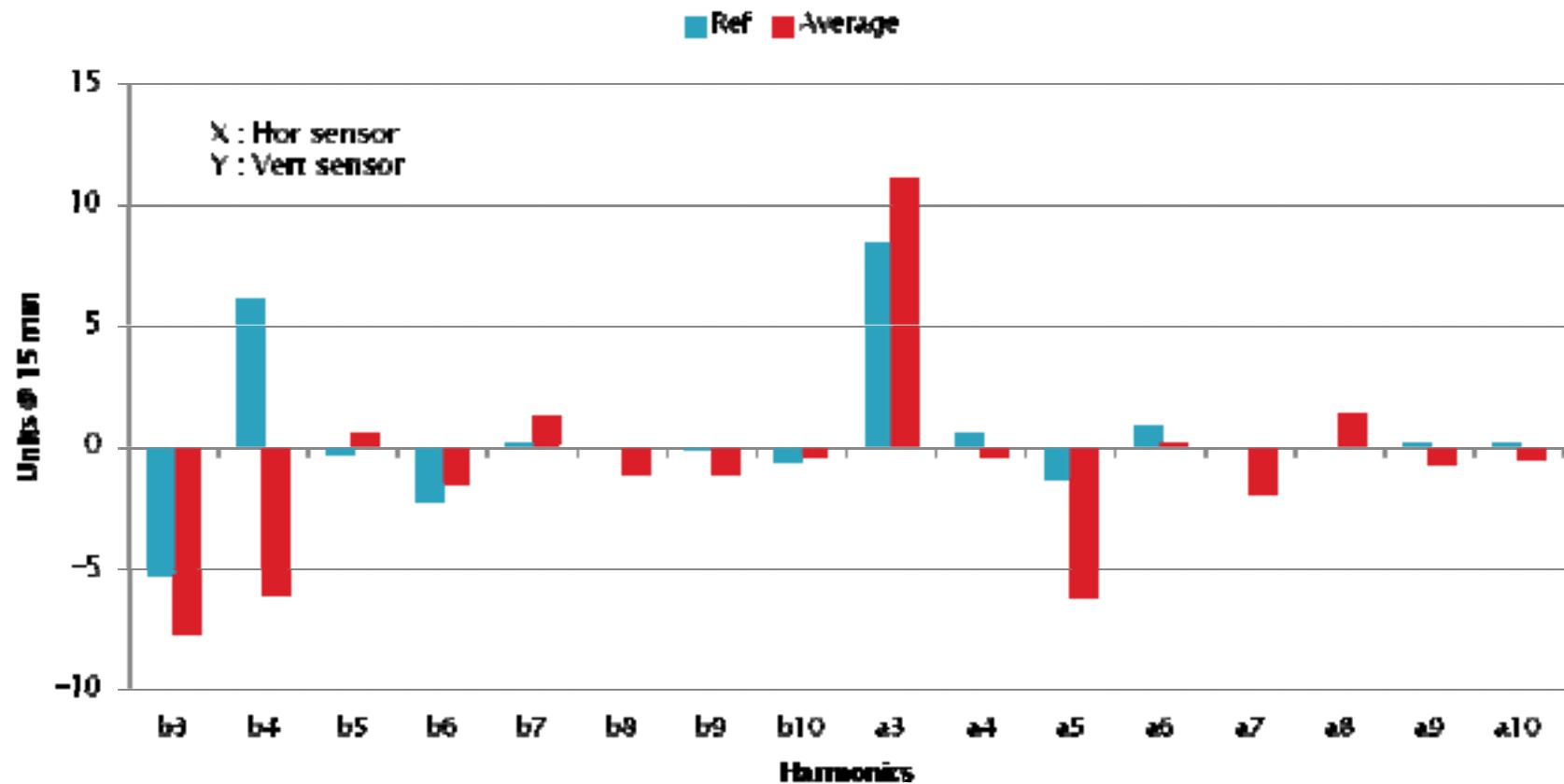
Geometrical pole measurement with Single Streched Wire + Optocoupleur



- ◆ Axis finding: Minimizing the amplitude vibration at resonant frequency and biggest AC current (105 mA) the sensitivity we have is better than 0.1 μm
- ◆ Problem : result in Local reference system. Precision lost when translating to magnets fiducials (~0.05 mm)
- ◆ Approach 1 : Geometrical pole profile measurement with stretched wire touching the surface (sensitivity with optocoupleurs 0.1 μm)
- ◆ Approach 2 : gauge equipped with optocoupleurs mounted in the magnet ends to measure the position of the wire

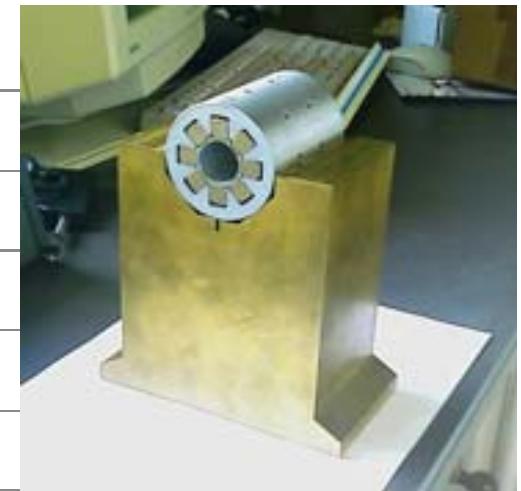
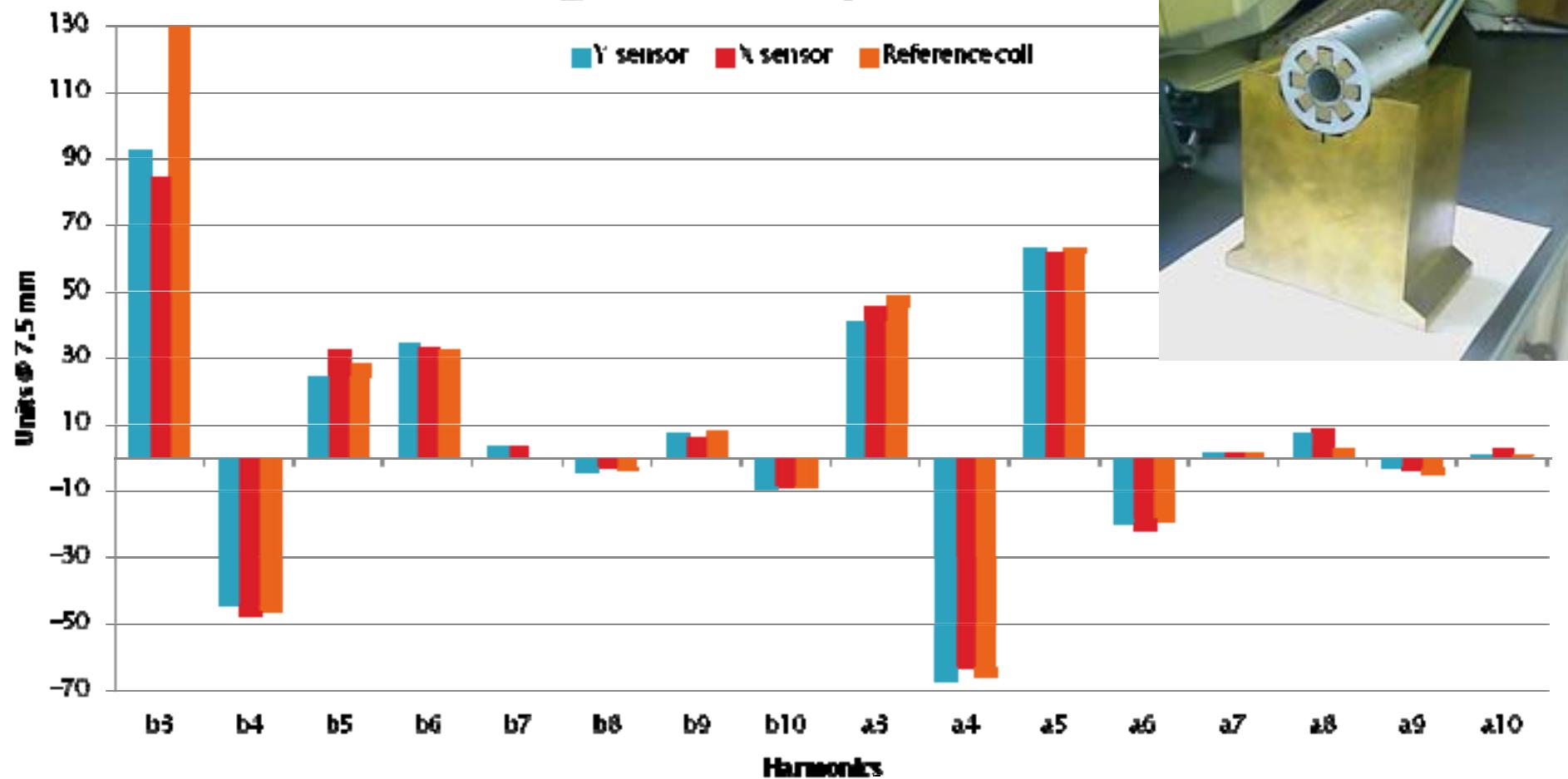


Harmonics results for Permanet Magnet Quadrupole



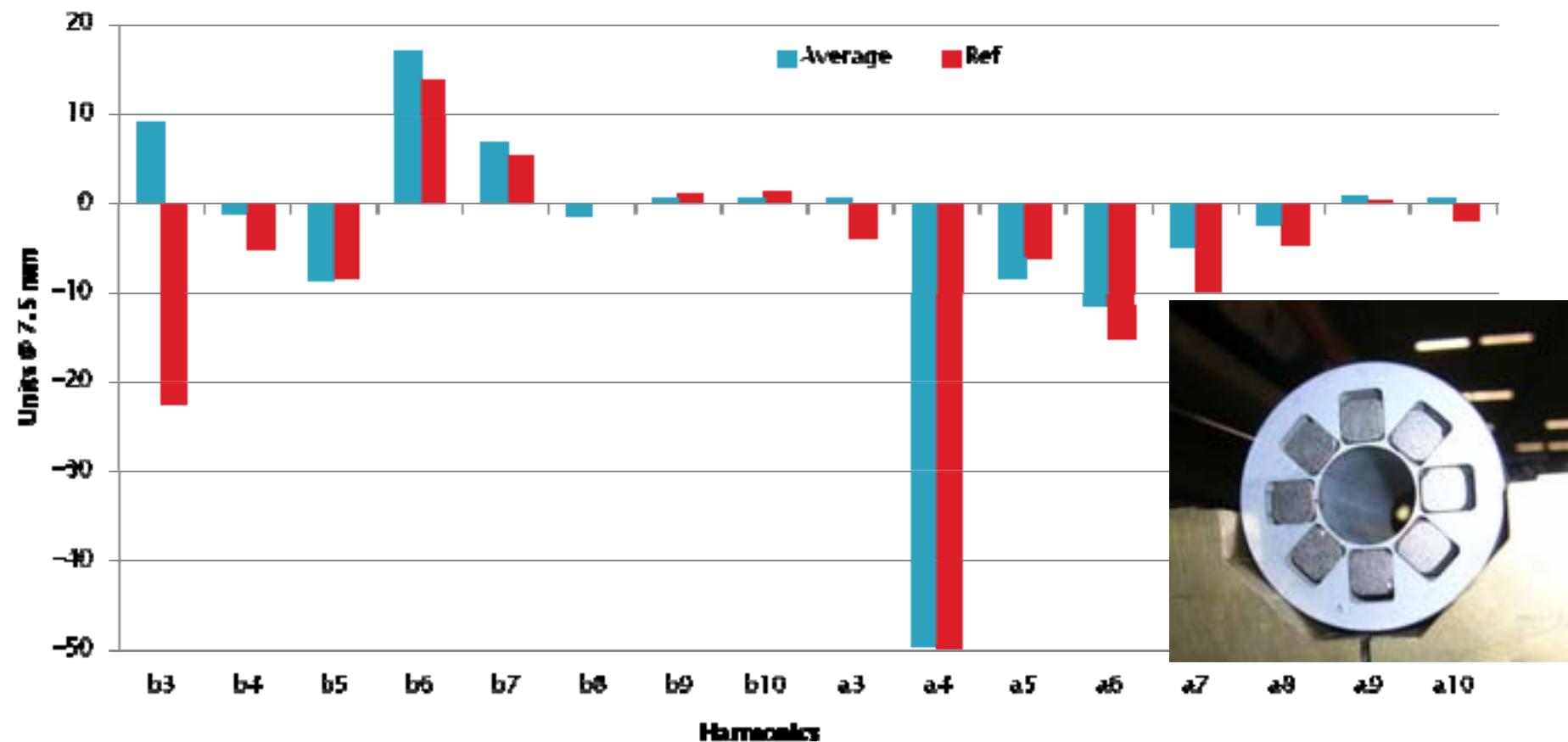
Harmonics	b3	b4	b5	b6	b7	b8	b9	b10	a3	a4	a5	a6	a7	a8	a9	a10
X	-48.7	-0.3	-1.1	-2.2	1.5	-1.5	-2.1	-0.5	11.3	-0.6	-6.1	-0.4	-0.5	1.8	-0.1	-1.3
Y	33.4	-11.7	2.1	-0.7	1.0	-0.7	0.0	-0.4	10.9	-0.2	-6.3	0.7	-3.3	0.9	-1.4	0.2
Average	-7.7	-6.0	0.5	-1.5	1.2	-1.1	-1.1	-0.4	11.1	-0.4	-6.2	0.1	-1.9	1.4	-0.7	-0.5
Ref	-5.2	6.1	-0.3	-2.2	0.1	0.0	-0.1	-0.6	8.5	0.5	-1.3	0.8	0.0	0.0	0.1	0.1
Cn X	50.0	0.7	6.2	2.3	1.5	2.3	2.1	1.3								
Cn Y	35.1	11.7	6.6	1.0	3.5	1.2	1.4	0.4								

R1 Linac 4 magnet comparison



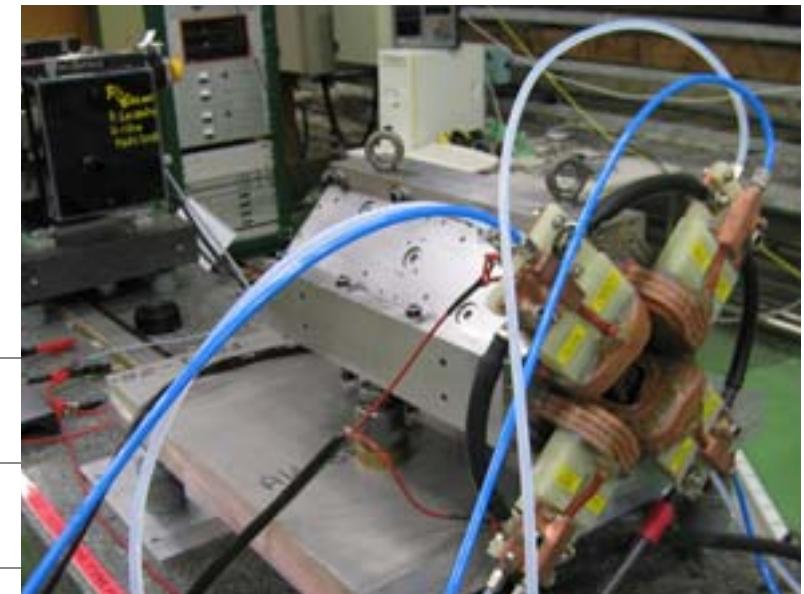
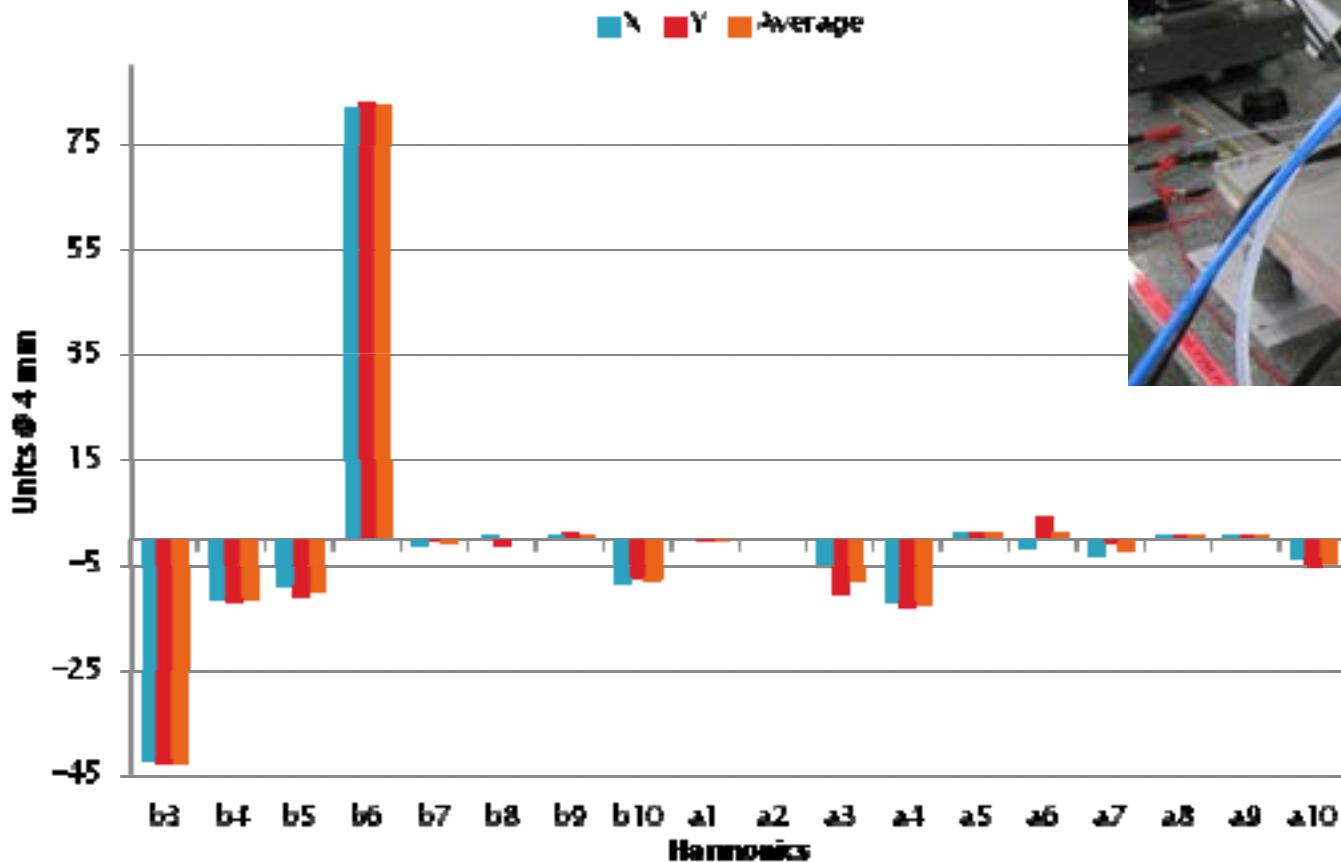
Harmonics	b3	b4	b5	b6	b7	b8	b9	b10	a3	a4	a5	a6	a7	a8	a9	a10
X	84.3	-47.5	32.6	32.7	3.7	-3.5	6.6	-8.9	45.7	-63.3	61.5	-22.1	1.4	9.0	-4.2	2.9
Y	92.5	-44.3	24.4	34.1	3.7	-4.6	7.6	-9.5	41.1	-67.6	63.3	-19.7	1.8	8.0	-3.0	0.9
Average	88.4	-45.9	28.5	33.4	3.7	-4.0	7.1	-9.2	43.4	-65.4	62.4	-20.9	1.6	8.5	-3.6	1.9
Ref	129.7	-46.8	27.9	32.0	-0.3	-4.1	8.0	-9.1	49.3	-65.9	63.4	-18.7	1.3	2.6	-5.5	1.1

ELYTT 80mm Linac 4 measurements



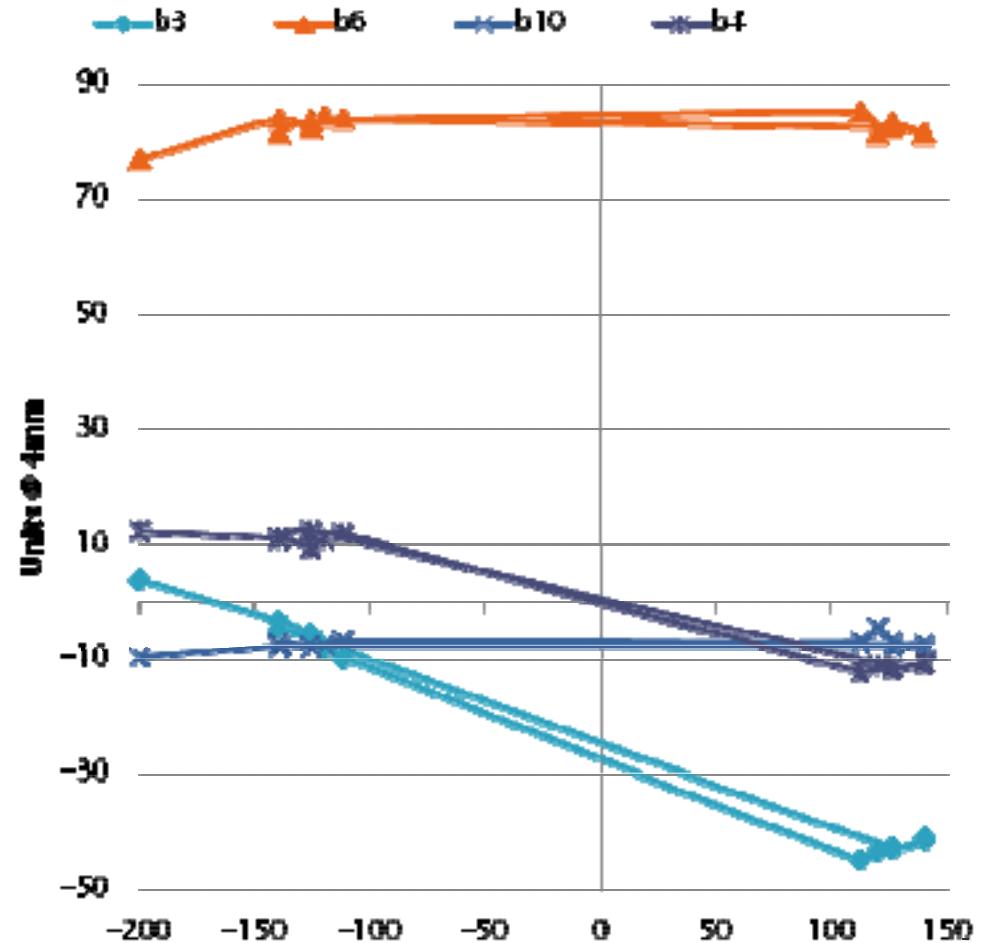
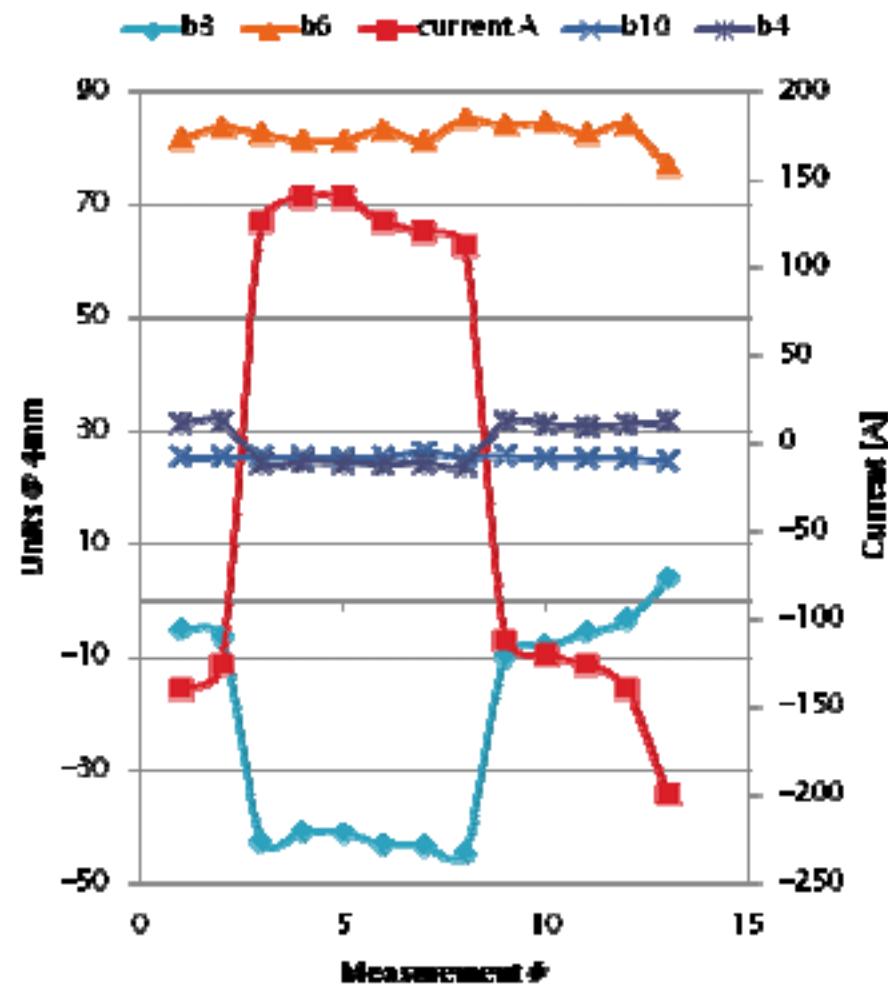
Harmonics	b3	b4	b5	b6	b7	b8	b9	b10	a3	a4	a5	a6	a7	a8	a9	a10
X	8,5	-7,4	-9,8	16,3	6,5	-1,5	0,7	-0,2	2,3	-50,7	-7,6	-12,0	-5,2	-2,3	0,5	0,7
Y	9,8	5,5	-7,6	17,8	7,2	-0,7	0,3	1,0	-1,1	-48,3	-9,2	-10,7	-4,3	-2,2	1,1	0,1
Average	9,2	-1,0	-8,7	17,1	6,8	-1,1	0,5	0,4	0,6	-49,5	-8,4	-11,4	-4,8	-2,2	0,8	0,4
StdevX	1,6	1,0	1,6	1,5	1,4	0,9	1,0	1,0	2,1	1,2	2,3	1,3	1,2	1,0	0,9	0,8
Ref	-22,4	-5	-8,4	13,7	5,3	0	1	1,4	-3,8	-49,8	-6,1	-15,1	-9,7	-4,5	0,4	-1,7

Mean Beam Quadrupole CLIC T1 prototype measurements

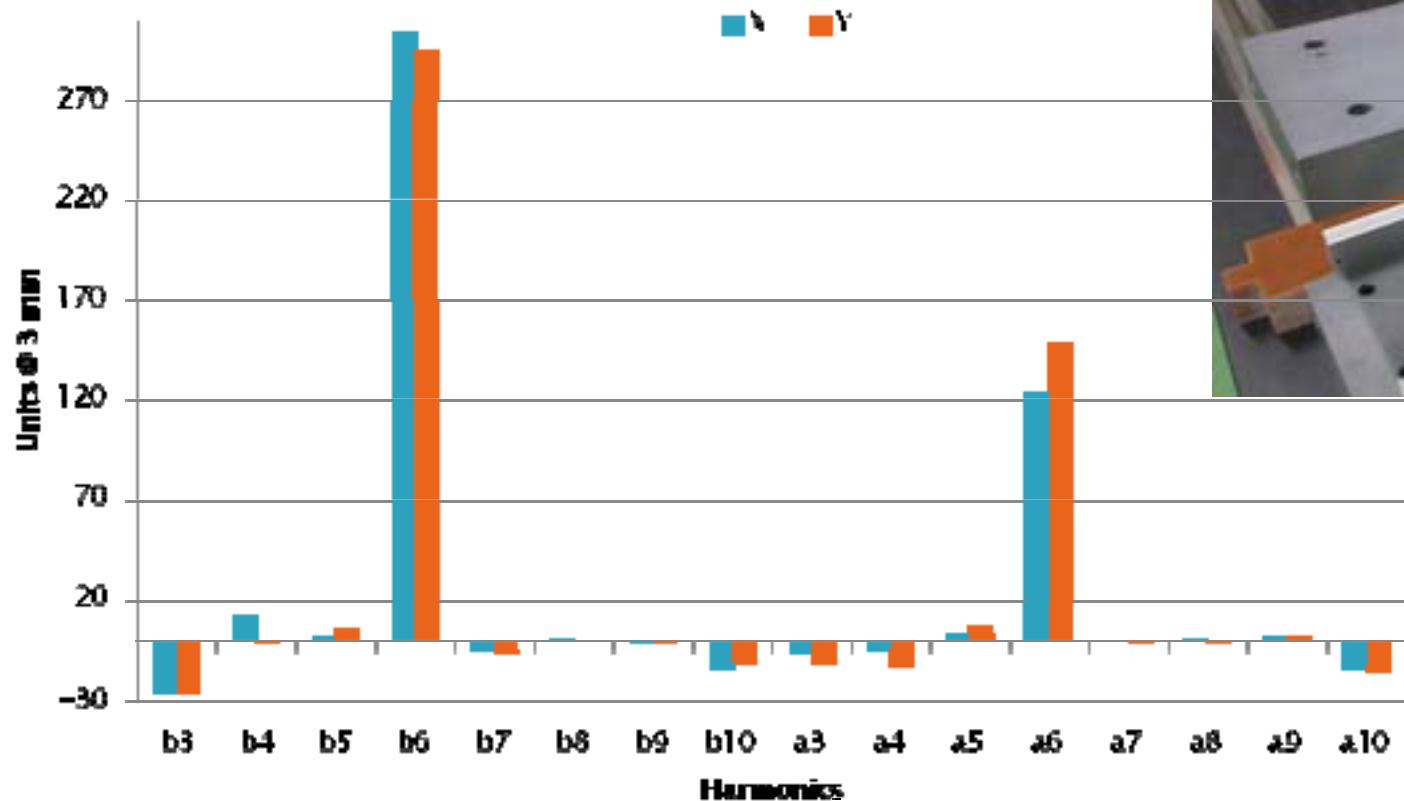


- ◆ 334 mm length
- ◆ 70 T integrated gradient
- ◆ 126 A nominal current
- ◆ 10 mm diameter aperture

Current cycle harmonics results



Hybrid Final Focus Quadrupole prototype for CLIC



- ◆ 8 mm diameter aperture
- ◆ 100 mm length
- ◆ Nominal gradient 500 T/m
- ◆ 15 A nominal current

Harmonics @ 3 mm	b3	b4	b5	b6	b7	b8	b9	b10	a3	a4	a5	a6	a7	a8	a9	a10
X	-25.1	13.1	1.5	305.0	-4.6	1.0	-0.6	-14.6	-5.5	-4.6	3.2	123.0	0.3	1.0	1.4	-13.3
Y	-25.1	-0.2	6.7	295.0	-5.5	0.3	-1.2	-11.0	-10.5	-11.8	7.3	148.6	-0.1	-0.3	1.4	-15.1
Average	-25.1	6.5	4.1	300.0	-5.1	0.6	-0.9	-12.8	-8.0	-8.2	5.2	135.8	0.1	0.3	1.4	-14.2
Cn	26.5	12.9	6.7	329.5	5.1	0.9	1.7	19.2								
Cn Ref	14.3	23.6	138.6	427.8	10.2	4.8	48.5	215.0								

Ref. coil measurement : O. Dunkel presentation at this workshop

Conclusions

- ▶ LINAC4 system operational and ready for pulsed magnets
- ▶ Axis measurements Ok and new ideas to be tested
- ▶ SSWW harmonics method gives very interesting results
- ▶ Challenge of very small apertures seems to have solutions
- ▶ Still work to understand better the system
- ▶ A new system to be developed with the knowledge acquired

